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## DEVELOPMENT OF HARD AND POROUS CARBON MATERIAL "RB CERAMICS" USING RICE BRAN AS A STARTING MATERIAL

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A hard and porous carbon material "RB ceramics", which has recently developed and is obtained from rice bran as a starting material, exhibits a variety of characteristic properties as an environmentally adaptable, multi-functional and high-performance material. Background of development, preparing method, characteristics, application of RB ceramics and the like will be described in this article.

### 1. Introduction

A joint research and development of a novel porous carbon material "RB ceramics" obtained from a dewaxed product of rice bran as a starting material has been conducted between Hokkirigawa laboratory in Department of Mechanical System Engineering, Faculty of Engineering, Yamagata University and Sanwa Yushi Co., Ltd.<sup>1,2)</sup>. RB is abbreviation of an English term "Rice Bran". RB ceramics exhibits a variety of characteristic properties as an environmentally adaptable, multi-functional and high performance material. Background of development, preparing method, characteristics, application of RB ceramics and the like will be briefly described in the following.

### 2. Background of RB ceramics development

Responding to a demand of industrial society to develop materials of higher quality and improved functions, modern

material science has been advanced in widely and variously subdivided fields. However, material science is confronted with global environmental issues as a serious problem and begins to grope for its future toward 21<sup>st</sup> century to consolidate different fields freely from conventional frameworks. It is now a great turning point to get away from a bulk consumption and difficulty in recycling of petroleum resources such as plastics and various kinds of composite materials, as well as development of materials which cause mass production of industrial wastes and to shift toward development of those materials which are more adaptable to global environment and more easily recycled. New advancement in material science in 21<sup>st</sup> century is never achieved by a conventional manner of material development in which an attention is given to a specific function to be improved.

On the other hand, production of rice in the world is said to be about five hundred million ton a year <sup>3)</sup>. A bulk of husks and rice bran is produced from rice as by-products. It is estimated that an amount of rice bran thus produced in the world is about 33 million ton a year. While in Japan, more than ten million ton of rice and about 0.9 million ton of rice bran are produced a year. Production of steel as a main industrial material in Japan is about one hundred million ton a year. Rice bran is only about 1 % by weight of steel, but is 15 % or so by volume thereof. Accordingly, rice bran is an abundant resource of plant origin.

Rice bran contains about 20 % by weight of fatty components. About 0.4 million ton of rice bran is currently used to produce rice bran oil and wax, while the rest is applied to feed, medium for growing mushroom, pickling paste, etc. An amount of dewaxed rice bran after oil extraction reaches not less than 0.3 million ton a year in Japan. Such dewaxed rice bran is simply used as agricultural materials such as feed and fertilizers, and thus strongly expected to put it more effective use.

If dewaxed rice bran can be utilized as a new industrial material, it should be used as an ecological and high technical product of plant origin (advanced industrial material of environmental acceptability) which is quite different from

conventional industrial materials.

On the basis of the above mentioned background, the present research and development has been carried out for the purpose of effectively utilizing rice bran as a new industrial material.

### 3. Method for preparing RB ceramics

RB ceramics is a completely new hard and porous carbon material prepared by mixing dewaxed rice bran with a phenol resin, molding the mixture and baking in an atmosphere of nitrogen gas at a temperature of 300 to 1,100°C to form a carbonized product as shown in Fig. 1. A sample of RB ceramics is shown in Photo 1. RB ceramics comprises soft amorphous carbon and hard glassy carbon which reinforces around the amorphous carbon as the main ingredients.

According to the above mentioned method, granular rice bran can be formed into a molded product, while it is also possible to yield various properties through carbonization and baking, which allows rice bran to effectively use as a new industrial material. There may be used the other kinds of bran such as wheat bran ( by-product of wheat) and rice hulls as a starting material. The starting material used in the present method is a dewaxed product of rice bran as a residue after an edible oil or wax is recovered therefrom, which makes it possible to effectively use rice bran in various fields.

### 4. Difficulties encountered in the course of RB ceramics development

In the beginning, it was difficult to prepare a molded product sufficiently practical as an industrial material due to a gas (or smoke) generated in a large amount during a carbonizing and baking process, a part of which is left in the product to cause cracking. However, a RB ceramics molded product capable of completely controlling the occurrence of cracking and of high strength and hardness as well as stable quality has been obtained

by sufficiently and accurately controlling particle size of rice bran, content of a phenol resin, molding condition, baking temperature program, etc.

## 5. Properties of RB ceramics

RB ceramics has excellent properties as an industrial material as in the following.

### (1) High hardness

In Fig. 2, there is shown a relationship between carbonizing temperature and Vickers hardness of RB ceramics. It is apparent from Fig. 2 that RB ceramics exhibits quite high hardness at a carbonizing temperature of 700°C or higher. Vickers strength of conventional industrial materials is, for example, 5 to 20 in charcoal; 20 to 100 in aluminum; 200 to 300 in general steel, and 500 to 800 in quench-hardened steel. The averaged Vickers strength of RB ceramics is 400 to 600, while the maximum value is 1,000 or higher. That is to say, RB ceramics has remarkably high hardness comparable with quenched steel.

### (2) High strength

Compression strength of RB ceramics is 70 to 80 MPa (bearable against 700 to 800 kg/cm<sup>2</sup> in weight), which is very high strength as a porous material.

### (3) Low density (light in weight)

A relationship between carbonizing temperature and density of RB ceramics is shown in Fig. 3. It is obvious that density of RB ceramics is not higher than 1.3 g/cm<sup>3</sup> at any carbonizing temperature and is very low as that of water. Thus, the RB ceramics molded product is characteristically lighter in weight compared with either of metal, ceramics or plastics of the same volume.

### (4) Porous structure

A large amount of gas is generated at carbonizing and baking temperature of RB ceramics around 300 to 500/cm<sup>2</sup>. Thereby, a great number of fine pores of several 10 micron or less in diameter are formed, which function as loopholes for the gas

generated inside of the carbonized product so that occurrence of cracking thereof due to inside gas pressure is controlled. The thus formed porous structure yields characteristics of high hardness and lightness in weight. It takes a vast time to carbonize a resin alone so as to control cracking because of absence of such porous structure, while thickness of the resin to be carbonized is limited. As RB ceramics has porous structure, it possible to carbonize into a hard material in a short period of time and yield a molded product of 20 mm or more in thickness.

(5) Easily molding and fabricating characteristics prior to baking

Dewaxed rice bran is kneaded with a phenol resin, which can be easily and variously molded, such as by injection molding, and mechanically fabricated after molding, such as by cutting and grinding, under a condition of low energy. Accordingly, it is possible to fabricate products of complicated shapes at low cost.

(6) Low friction properties

There is shown a relationship between carbonizing temperature and friction coefficient of RB ceramics in Fig. 4. Using a friction pair of RB ceramics plate and alumina sphere of 1.5 mm in diameter, a friction experiment was conducted under a lubrication-free condition in the air with loading of 0.98 N at sliding velocity of 5 mm/second. It is clear that RB ceramics baked at a temperature of 500°C or higher shows a very low value, i.e., friction coefficient of about 0.13 to 0.17 under a lubrication-free condition. Further, the friction coefficient is quite stable without exhibiting considerable fluctuation, which is effective to control noise or frictional vibration. RB ceramics shows low friction coefficient in water similarly as in the air.

(7) Excellent friction resistance

RB ceramics baked at a temperature of 700°C or higher shows excellent friction resistance under a lubrication-free

condition, which is about 1,000 times higher than that of steel.

(8)Excellent corrosion resistance

RB ceramics has excellent properties against corrosion because of a carbon material in nature. Especially, this material hardly deteriorates in water.

(9)Abundance of starting materials (resources)

As 0.9 million ton of rice bran (or 0.3 million ton of dewaxed rice bran) is produced as a byproduct of rice repeatedly every year in Japan, the starting material is abundant and its stable supply can be secured domestically.

(10)Adaptability to natural environment

As RB ceramics can be prepared by effectively utilizing an agricultural plant resource by-produced every year and does not cause natural environmental damage as a waste, this material is also quite excellent from a viewpoint of ecology. If RB ceramics can be used as a substitute of wood or wood based materials in the future, worldwide deforestation will be controlled.

6. Uses to be expected

Useful application of RB ceramics to be expected at present is as in the following.

(1) Sliding (friction) material

RB ceramics exhibits low friction properties and excellent abrasion resistance, which are applicable to various kinds of sliding (friction) components. RB ceramics may be conveniently used under a condition of lubrication-free or oil-free in water after use, and also effectively used by impregnating a lubricant while making the most of porous structure thereof.

(2) Shielding material for electromagnetic wave

It is expected to use RB ceramics as a shielding material for electromagnetic wave because of its porous structure made of carbon material.

(3) Heating element

Electric resistance of RB ceramics can be widely changed from a state to be regarded as an electrically insulating material to a state to be regarded as an electrically conductive material,

which makes it possible to apply the above mentioned material as a heating element (heater).

(4) Others

Further, it is expected to use RB ceramics as a substitute of structural materials such as wood and wood based materials. Especially, RB ceramics is easily molded and fabricated prior to baking and is exceedingly heat resistant up to about 400°C after baking, which would allow to further widen its uses.

## 7. Conclusion

RB ceramics starting from rice bran is an ecological material especially in Japan living on rice. This means that agriculture is sociologically positioned not only as a food supplier but also as an industrial supplier, although RB ceramics is provided to the industry as a new material. More proper conditions of RB ceramics production for specific applications will be revealed as a result of wide cooperation with those skilled in the related field, while this investigation will be advanced toward its practical use.

## References

- 1)Kogyou Zairyou (Industrial Material), 45 (1), 15 Nikkan Kogyou Shinbunsha (Daily Industry Newspaper Co., Ltd.)
- 2)Kazuo Hokkirigawa, Gekkan Toraiboroji (Monthly Tribology), No. 113, 45 (1997)
- 3)Shinjiro Takeo (Supervisor); Kiyu Ishitani and Kenichi Otsubo (Editor), Kome no Kagaku (Rice Science), pp. 5, Asakura Shoten (1995)

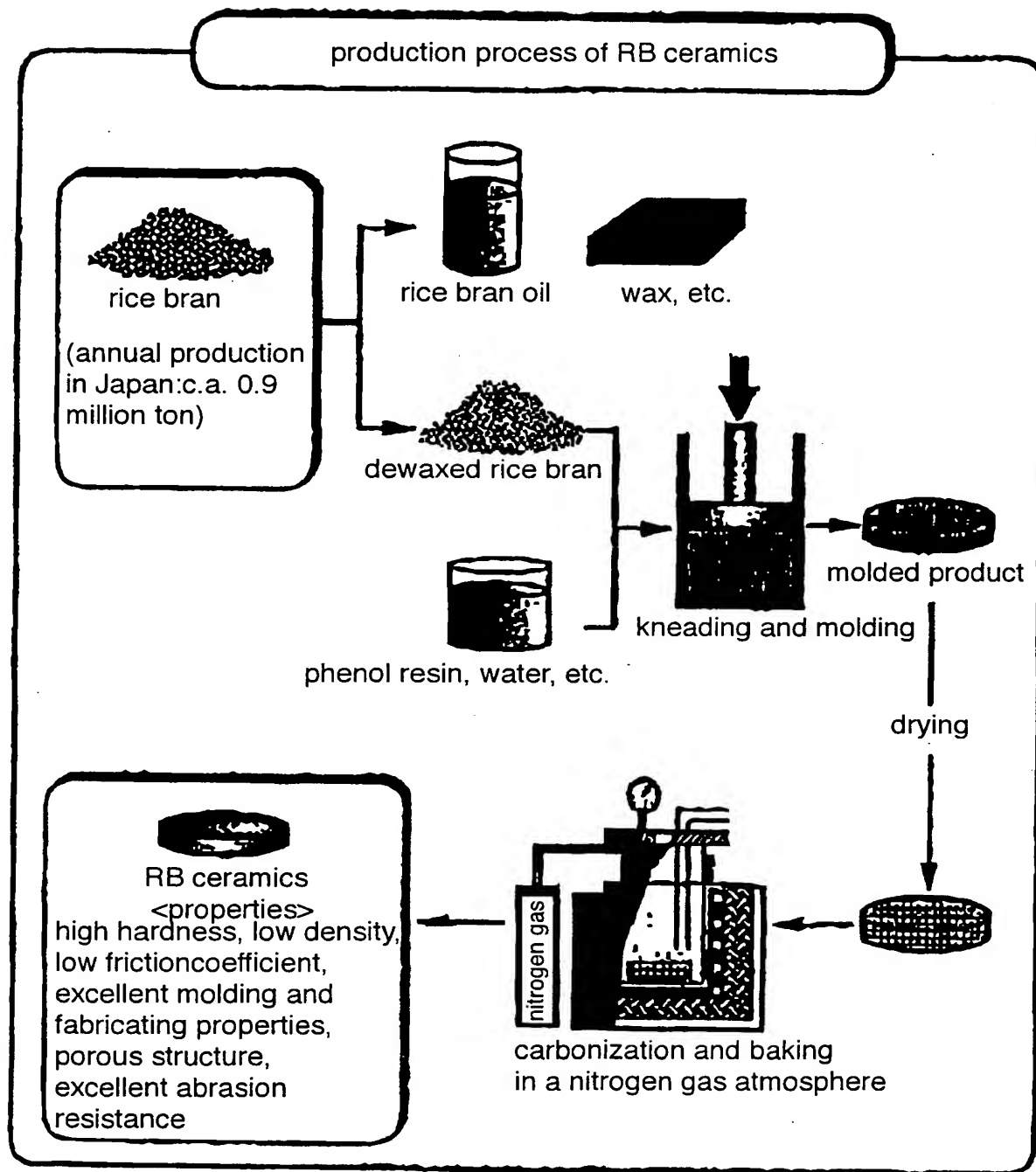


Fig. 1 Outline of RB ceramics production process

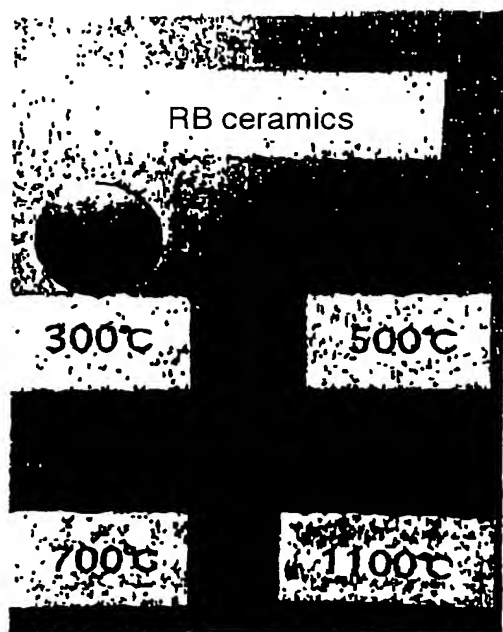


Photo 1 Example of RB ceramics preparations

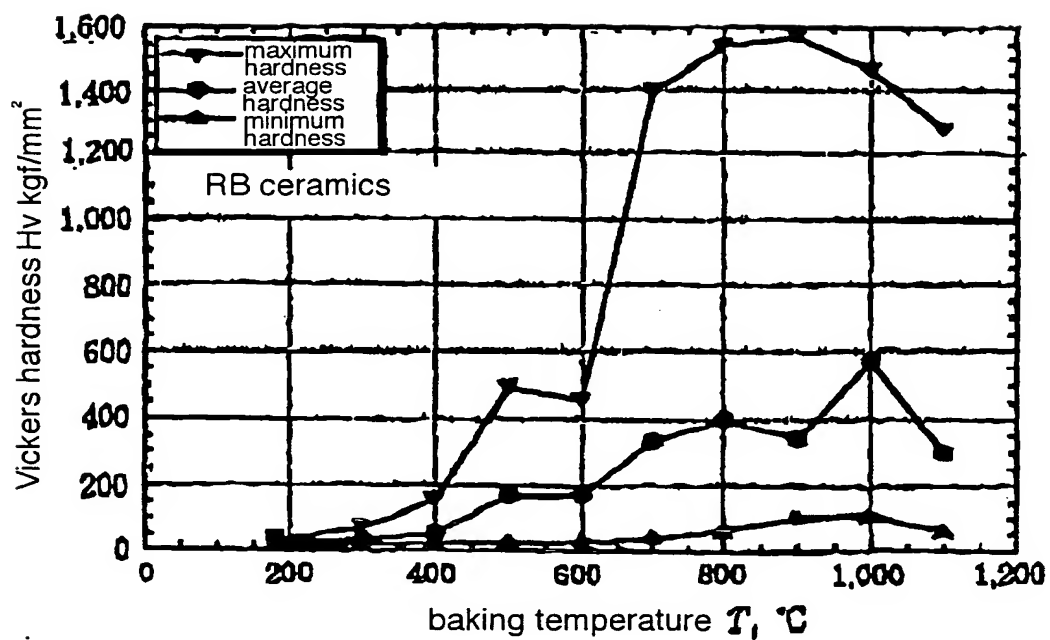


Fig. 2 Relationship between baking temperature and Vickers hardness of RB ceramics



Photo 2 Scanning  
electron photomicrography of RB ceramics

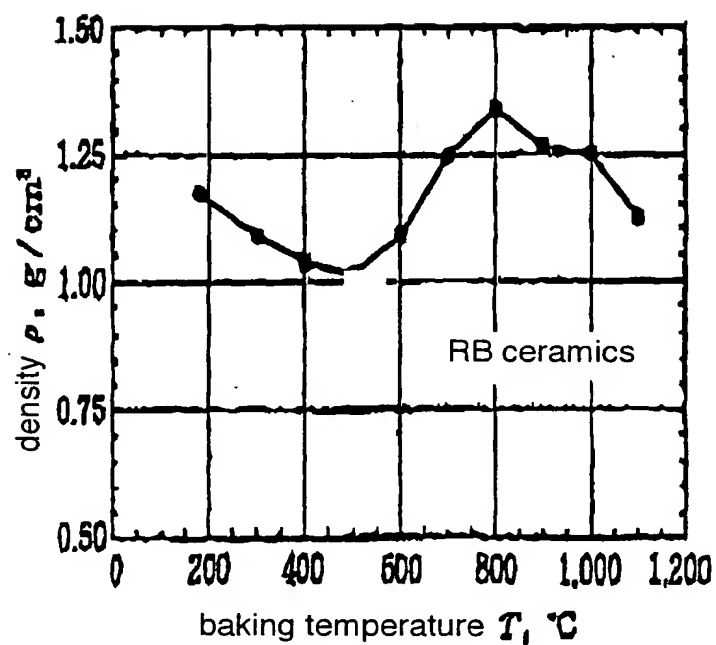


Fig. 3 Relationship between baking  
temperature and density of RB ceramics

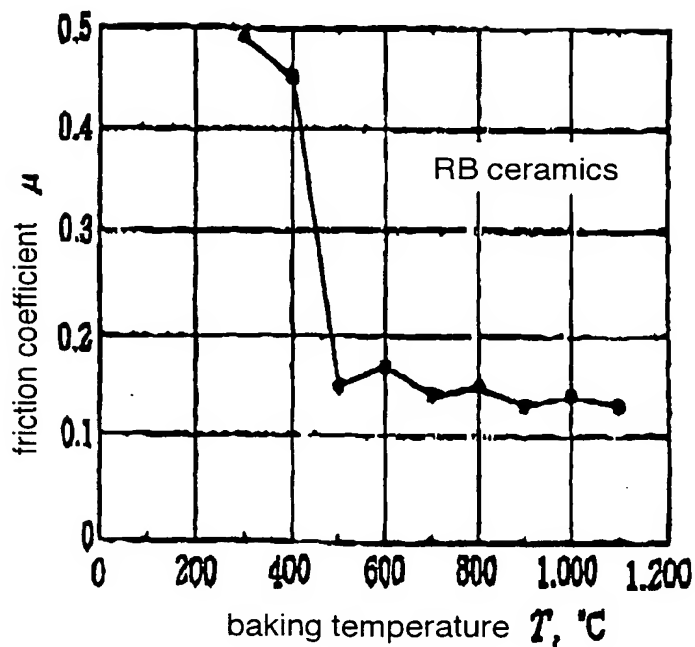


Fig. 4 Relationship between baking  
temperature and friction coefficient of RB cerar